AD-A166 182 NONLINEAR OPTICAL INTERACTIONS IN SEMICONDUCTORS(U) 1/1
TACAN AEROSPACE CORP CARLSBAD CA M M SALOUR 10 DEC 85
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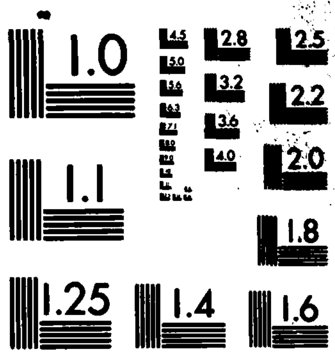

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We have completed our optical pumping technique in GaAs ~~which~~ has led to the development of a novel and highly sensitive optical temperature sensor. ~~We have also~~ completed ~~our~~ experiment on two-photon optical pumping in ZnO. An external cavity semiconductor laser involving ZnO as a gain medium was demonstrated under two-photon excitation. This laser should have a major impact on the development of tunable blue-green radiation for submarine communication. ~~We have~~ completed ~~our~~ paper on heat buildup in semiconductor platelets, (Electronics Letters, Vol. 21, No. 4, 135, (1985) and are in the process of completing another article for publication. In addition, we have made four invention disclosures to the U.S. Air Force. We received the delivery of two large laser systems along with a variety of test and measurement equipment to enhance the current research under this contract. We utilized these lasers to explore elementary excitation in optical thin film layers of semiconductors. This has led to the first demonstration of the feasibility of room temperature operation of a tunable coherent source involving multiple

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quantum well material. An invention disclosure has been filed with the U.S. Air Force Patent Office for work performed on multiple quantum well material under this contract. We have completed the construction of a simple remote (non-contact) temperature sensor to directly measure heat buildup in semiconductor materials as a result of high power optical laser excitation, as proposed in part F of our research proposal. Finally, an experiment involving optical frequency mixing to probe electrodynamics in the GaAlAs multiple quantumwell and superlattice structures, utilizing our two recently constructed tunable laser systems, has been sucessful. ~~Our~~ attempts were focused on observing a number of new optical effects including nonlinear absorption and transmission phenomena,enhanced spontaneous and stimulated light scattering processes, etc. The construction of an external cavity semiconductor HgCdTe has been sucessful. This has allowed us to undertake a careful study of multi-photon optical pumping in semiconductors to generate IR radiation and a variety of studies involving HgCdTe narrow-gap semiconducting compouds outlined in our proposal.

FINAL REPORT

on

NONLINEAR OPTICAL INTERACTIONS IN SEMICONDUCTORS

U.S. Air Force Contract #F49620-83-C-0147

August 10, 1983 to December 31, 1985

Principal Investigator

Michael M. Salour

TACAN Aerospace Corporation

2111 Palomar Airport Road, Suite 100

Carlsbad, CA 92008

ABSTRACT

We have completed our optical pumping technique in GaAs which has led to the development of a novel and highly sensitive optical temperature sensor. We have also completed our experiment on two-photon optical pumping in ZnO. An external cavity semiconductor laser involving ZnO as a gain medium was demonstrated under two-photon excitation. This laser should have a major impact on the development of tunable blue-green radiation for submarine communication.

We have completed our paper on heat build up in semiconductor platelets [Electronics Letters, Vol. 21, No. 4, 135, (1985)] and are in the process of completing another article for publication. In addition, we have made four invention disclosures to the U. S. Air Force.

We received the delivery of two large laser systems along with a variety of test and measurement equipment to enhance the current research under this contract. We utilized these lasers to explore elementary excitation in optical thin film layers of semiconductors. This has led to the first demonstration of the feasibility of room temperature operation of a tunable coherent source involving multiple quantum well material. An invention disclosure has been filed with the U.S. Air Force Patent Office for work performed on multiple quantum well material under this contract.

We have completed the construction of a simple remote (non-contact) temperature sensor to directly measure heat buildup in semiconductor materials as a result of high power optical laser excitation, as proposed in Part F of our research proposal.

Finally, an experiment involving optical frequency mixing to probe electron dynamics in the GaA1As multiple quantum well and superlattice structures, utilizing our two recently constructed tunable laser systems, has been successful. Our attempts were focused on observing a number of new optical effects including nonlinear absorption and transmission phenomena, enhanced spontaneous and stimulated light scattering processes, etc. The construction of an external cavity semiconductor HgCdTe has been successful. This has allowed us to undertake a careful study of multi-photon optical pumping in semiconductors to generate IR radiation and a variety of studies involving HgCdTe narrow-gap semiconducting compounds outlined in our proposal.

I. Research Objectives

The aim of this program was to investigate a variety of novel, nonlinear optical processes in semiconductors. These ideas combined ultra fast spectroscopic techniques to probe the basic physics of the interaction of intense subpicosecond pulses with semiconductor systems. Ultimately, we used these interactions as the basis for ultra fast, cw, tunable infrared sources. Among the processes we studied, were the following:

A. Multi-photon optical pumping in semiconductors to generate IR radiation, eg., narrow-gap semiconducting compounds such as $Hg_{1-x}Cd_xTe$.

B. Generation of high-power coherent infrared (2μ with possible extension to 100μ) radiation using multi-photon pumping in external cavity, with narrow-gap semiconducting compounds.

C. Infrared nonlinear optical processes in a traveling-wave ring cw laser of narrow-gap semiconducting compounds for generation of coherent infrared/submillimeter tunable radiation.

D. Studies with a cw $Hg_{1-x}Cd_xTe$ laser in the infrared.

E. Basic dynamics of electron-hole plasma in generating heat in semiconductor materials.

F. Methods of preparing optical thin film layers by laser techniques to reduce chirp in picosecond pulses from IR semiconductor lasers.

G. Electron-photon relaxation time and coupling constants in semiconductors.

H. Elementary excitations in polariton (electron-hole-photon) induced group-velocity dispersion in solids.

II. Accomplishments

We have successfully completed our experiment on two-photon optical pumping in ZnO. In addition, we have developed an external cavity semiconductor laser involving ZnO as a gain medium under two-photon excitation. This laser should have a major impact on the development of tunable blue-green radiation for submarine communication. A paper presenting a detailed analysis of the research involving the advantages of two-photon pumping in bulk, heterostructure and multiple quantum well material is under preparation.

Our studies of infrared nonlinear optical processes in a traveling-wave ring cw laser of narrow-gap HgCdTe semiconducting compounds have been successful. During the past year, we have succeeded in constructing a state-of-the-art ring cavity (Part 3 under Statement of Work). The advantage of our new configuration is that it can be operated at room temperature using GaA1As multiple quantum well material and with lower optical powers than existing semiconductor lasers. Furthermore, it can provide tunable coherent output. We have made an invention disclosure to the U.S. Air Force for this novel system. The gain medium consists of an active media of multiple quantum well (MQW) material composed of approximately 100 layers of semiconductor to form many periods of a layered structure. The external cavity operation allows mode-locked, pulsed or continuous operation and independent control of the output, power and frequency.

Our invention provides several novel features: (1) It has a long shelf life and should not undergo thermal or photochemical degradation. (2) It is operable as a laser at room temperature as well as at temperatures above or below room temperature. (3) In contrast to dye lasers, there are no pressure or jet fluctuations. (4) By the use of a variety of semiconductors to form the multiple quantum well, we will not be restricted to those materials that can be formed as p-n junctions. The experimental work is still underway and a few papers providing a detailed analysis of the research will be completed during the next few months.

Our studies of basic dynamics of electron-hole plasma in generating heat in semiconductor materials (Part 5 under Statement of Work) has been successful. To make a systematic measurement one needs a very sensitive temperature sensor. We

made an invention disclosure for a fiber optic temperature sensor which utilizes a semiconductor sample as a sensing media. Light is guided in an optical fiber to the semiconductor sample and back to the analyzing electronics. The band gap energy of the semiconductor decreases with increasing temperature. Consequently, the absorption of light in the energy region of the band gap changes with temperature. From the measured light absorption, the temperature of the semiconductor sample can be calculated. The above sensor can operate in an environment of changing high electric or magnetic field without being influenced by those environmental perturbations. A detailed analysis and description of the invention is summarized in the invention disclosure and in a paper recently published in Electronics Letters, Vol 21, No. 4, 135, (1985).

Using TACAN's internal funds, we received the delivery of two large laser systems along with a variety of test and measurement equipment to enhance the current research under this contract. We have utilized these lasers to explore elementary excitation in optical thin film layers of semiconductors. Also, we have demonstrated the feasibility of room temperature operation of a tunable coherent source involving multiple quantum well material. An invention disclosure has been filed with the U.S. Air Force Patent Office for work performed on multiple quantum well material under this contract.

We have completed the construction of a simple remote (non-contact) temperature sensor to directly measure heat buildup in semiconductor materials as a result of high power optical laser excitation, as proposed in Part F of our research proposal.

Finally, an experiment involving optical frequency mixing to probe electron dynamics in the GaA1As multiple quantum well structures, utilizing our two recently constructed tunable laser systems, has been successful. Two such lasers at frequencies ω_1 and ω_2 transverse to a GaA1As superlattice structure, induces an AC current in the electron gas and, more importantly, will modulate the electron energy at the difference frequency, $\omega_1 - \omega_2$. Under ordinary circumstances such an energy (or temperature) modulation has relatively little effect. If, however, the sample is in a sizable DC field, so that some carriers have spilled from the central conduction band valley to subsidiary minima, a temperature modulation can have a large effect. In particular, it will alter the ratio of light to heavy mass carriers [assuming $(\omega_1 - \omega_2)$ is

smaller than the inter valley scattering rate], creating a dielectric constant modulation which then gives rise to four-photon mixing. Our attempts were focused on observing a number of new optical effects including nonlinear absorption and transmission phenomena, enhanced spontaneous and stimulated light scattering processes, etc. The construction of an external cavity semiconductor laser has been completed. This will allow us to undertake a careful study of multi-photon optical pumping in semiconductors to generate IR radiation and a variety of studies involving narrow-gap semiconducting compounds outlined in our proposal. An article describing detailed analysis of this experiment is currently under completion.

III. Invention Disclosures

1. Semiconductor platelet–based fiber optic temperature sensor.

2. Optically pumped room temperature narrow–gap semiconductor laser using superlattice as a gain medium.

3. Fiber–coupler for use in a fiber optics transmission sensor, where the fibers that guide the light to the sensor and back are parallel.

4. Semiconductor laser using gradient indexed gain structure.

IV. Publications

1. "Semiconductor Platelet Fiber Optic Temperature Sensor", M. M. Salour, G. Schoner, M. Kull, and J. H. Bechtel, Electronics Letters, Vol. 21, No. 4, 135 (1985).

2. "Fringe Orientation of Diffraction Efficiency in Bismuth Silicon Oxide", M. M. Salour, C. L. Woods, C. L. Matson, submitted for publication in Applied Physics B (1985).

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6. Broadly Tunable Mode–Locked HgCdTe Lasers, R. S. Putnam, M. M. Salour, and T. C. Harman, Appl. Phys. Lett. 43, 408 (1983).

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9. Quantum Noise Measurements in Degenerate Four–Wave Mixing, P. Kumar, R. S. Bondurant, J. H. Shapiro, and M. M. Salour, in Coherence and Quantum Optics, V, (editors L. Mandel and E. Wolf) (Plenum, New York – 1983).

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This contract completed the work performed at M.I.T. by the principal investigator. Some experiments which were started at the principal investigator's laboratory at M.I.T. were completed at TACAN under this contract.

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V. Personnel

1. Mr. Herbert E. Grier, Chairman of the Board
2. Dr. Michael M. Salour, Principal Investigator
3. Dr. Bernd Valk, Research Scientist
4. Mr. Dick Bebelaar, Senior Electro–Optic Engineer (part–time)
5. Mr. Mark Haring, Mechanical Design Engineer
6. Mr. Walter Ganz, Design Electronic Engineer
7. Mr. James H. Bechtel, Senior Scientist
8. Dr. Gerhard Schoner, Post doctoral Fellow
9. Mr. Ulf Winstrom, Electo–Optic Engineer
10. Mr. Meinrad Steiner, Design Engineer
11. Mr. Stefan Anderssen, Electro–Optic Engineer
12. Mr. Martin Kull, Research Engineer
13. Mr. Joe Costa, Research Engineer
14. Mr. Tom Call, Mechanical Design Engineer
15. Ms. Joan I. Tukey, Contract Administrator
16. Ms. Jeanine H. Vandenberg, Adminis. Assistant to Principal Investigator
17. Ms. Leslie Marshall, Contract Administrative Assistant
18. Ms. Donna Wischnack, Contract Office Manager
19. Ms. Tammy Elam, Accountant
20. Ms. Donna Robb, Administrative Assistant to Principal Investigator

* Dr. James H. Bechtel resigned his position as TACAN's Senior Scientist, effective November 2, 1984, to devote more time to personal and family matters.

* Mr. Thomas S. Call, a Mechanical Design Engineer at TACAN, has devoted a major portion of his time on this contract. Mr. Call holds a Bachelor degree in Physics from Princeton University. He worked on his thesis under the direction of Professor William Happer, and has spent one year of his post–graduate studies in Japan.

* Dr. Bernd Valk, Research Scientist in Quantum Well technology, is currently working closely with the principal investigator at TACAN in implementing the use of various Quantum Well techniques.

* Mr. Dick Bebelaar is a Senior Electro–Optic Engineer in laser and electro–optic technology. Mr. Bebelaar holds several joint patents with the principal investigator and assisted the principal investigator with the proposed research on an intermittent part–time basis.

* Mr. Mark Haring is a mechanical design engineer at TACAN. Mr. Haring holds a B.S. degree in Opto–Mechanical Science and was responsible for the mechanical support in our laboratory under this program.

* Mr. Walter Ganz is an expert in digital and analog electronics and computer programming. Mr. Ganz holds a Bachelor of Science Degree in Electronic Design and his many years of experience was invaluable to the experimental aspect of our program.

* Ms. Joan I. Tukey, Contract Administrator and Chief Financial Office at TACAN, administers budget proposals and government contracts for the company. Ms. Tukey holds a Bachelor degree from the University of Minnesota and a Master of Science degree in Accounting from Georgetown University, Washington, D.C.

* Mr. John M. Malloy, a management consultant in the areas of operations and contract administration, interfaced with TACAN Aerospace Corporation with respect to contract management. Mr. Malloy holds an MBA from Harvard Graduate School of Business Administration.

* The accounting firm of Price-Waterhouse performed all internal audits for TACAN.

VI. Interactions with Government and Industry Laboratories

A. Dr. D. C. Reynolds, Wright-Patterson AFB, Ohio

Dr. Reynolds provided us with a large, excellent quality CdS and GaAs crystal for use in nonlinear optic experiments. The principal investigator visited Dr. Reynold's crystal growing facilities.

B. Professor N. Bloembergen, Harvard University

We collaborated with Professor Bloembergen and his research group at Harvard University. Professor Bloembergen visited our laboratory in LaJolla.

C. Professor W. D. Laidig, North Carolina State University

We had active interaction with Dr. W. D. Laidig of North Carolina State University in experiments involving multiple quantum well materials. A joint research paper for experiments performed at TACAN using his crystals is under completion.

D. Professor Hadis Morkoc, University of Illinois

We had on-going interaction with Professor Morkoc of the University of Illinois. We visited his crystal growing facilities and the availability of an MBE machine in his laboratory has made possible a number of joint efforts. We regularly discussed optical pumping and four-wave parametric mixing in multiple quantum well material and plan to publish together.

E. C.N.R.S., Physique du Solide et Energie Solaire

We had on-going interaction with Dr. Christian Verie on the growth of high quality narrow-gap semiconductor crystals of $Hg_{1-x}Cd_xTe$. Dr. Verie collaborated with the principal investigator on the growth of such crystals and we have discussed the possibility of a joint paper.

F. Professor P. T. Ho, University of Maryland

We had occasional contact with Professor Ho regarding mode-locking of semiconductor diode lasers for our AFOSR contract.

G. Dr. C. L. Woods, Rome Air Development Center, Hanscom AFB, MA

We had active collaboration with Dr. C. L. Woods of the RADC/ESOP at Hanscom AFB regarding optical excitation of hot carriers in narrow band gap semiconductors. A joint paper, entitled "Crystallographic Dependence of Voltage-Scaled Diffraction Efficiency in $Bi_{12}SiO_{20}$", has been completed and has been submitted for publication.

H. U.S. Air Force Weapons Laboratory, Kirkland AFB, Albuquerque, NM

A number of scientists, engineers and technical staff members at the U. S. Air Force Weapons Laboratory, Kirkland AFB, visited us to utilize the semiconductor lasers that we developed under the AFOSR contract. The high power and wide tunability range of our ring semiconductor laser led to the selection of this laser as the source of a widely tunable master oscillator at the USAF Weapons Laboratory. Dr. David Depatie and Dr. Phillip Peterson of Col. Thomas Walker's group are in the process of employing a ring semiconductor laser that we patented under an AFOSR contract operating in the blue/green-red region of the electromagnetic spectrum for a variety of applications in their laboratories. This laser is utilized as a master oscillator for a blue-green laser to designate the target from the air. The tunable red master oscillator laser is also utilized for optical countermeasure technology.

I. Wright-Patterson AFB, Dayton, OH

At Wright-Patterson AFB, our infrared laser has been identified as the only high power tunable source suitable for jet fuel combustion research. Dr. Alan Garscadden and Dr. B. Ganguly are putting together an optically pumped semiconductor laser developed and patented by the principal investigator under an AFOSR contract for operation in the range of 3μm – 5μm region. We will be assisting them in the construction of the device. This system will be utilized for the potential military application of IFF by using the proposed laser to examine the exhaust and thus identify the type of fuel used.

J. Rome Air Development Center, Hanscom AFB, MA

In addition to the development of nonlinear optical systems, our distortion-free fiber optic system is under consideration by Rome Air Development Center, Hanscom AFB (Dr. C. L. Wood and Dr. C. Pitha) for applications in communication security, and our fiber optic sensors are already in use for inertial navigation systems and a variety of aerospace applications (ultra sensitive measurements of temperature, pressure, magnetic field, etc.).

K. Industrial Laboratories

The ring HgCdTe semiconductor laser is under consideration for use by Honeywell and a few other industrial laboratories for wave conjugation to identify the target and "see" in bad weather, smoke, etc. This is exactly the same ring HgCdTe laser technology that we developed and patented under the AFOSR program. It is already in use for reconnaissance technology by the commercial industry.

We have occasional contact with a number of scientists at TRW (Los Angeles), Hughes Research Laboratory (Malibu, CA) and Hewlett-Packard Research Laboratory (Palo Alto, CA). We have received a number of enquiries from many other laboratories (both from the government and commercial industry) about the status of our optically pumped semiconductor laser and intracavity nonlinear optical techniques developed under our AFOSR contract. The principal investigator has given invited lectures at the above laboratories and a number of colloquium talks at various universities and government laboratories.

VII. Expansion in Facilities and Equipment

On April 1, 1984, TACAN Aerospace Corporation relocated its headquarters and laboratories to Carlsbad, California. This facility, located at 2111 Palomar Airport Road, Suite 100, contains laboratories which are specifically designed to accommodate a major expansion in our capital equipment pool. A number of large frame lasers, test measurement equipment, data processing systems, vibration free optical tables, crystal polishing facilities, fully equipped mechanical and electronic shops, etc. are part of this expansion. This expansion and the specialized capital equipment purchased by TACAN Aerospace Corporation provided a unique environment and a major enhancement to the productivity of our current research reported here.

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